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ScienceDirect
Energy Procedia 91 (2016) 824 – 831
Energy Procedia

SHC 2015, International Conference on Solar Heating and Cooling for Buildings and Industry

LEED™ Platinum awarded Arabian Green Building with solar heat driven cooling technology

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Abstract

A gigantic sustainable tourism project is taking shape in the city of Al Ain by order of the government in Abu Dhabi. The Sheikh Zayed Desert Learning Center SZDLC is the first constructed building of the masterplan and functions as museum and research centre for desert environments and ecological issues. The building-owner set ambitious targets for sustainability and energy efficiency and the SZDLC has been already certified in the US program LEED™ (Leadership in Energy and Environmental Design) with the LEED™ Platinum Standard. With this paper two parts of the pioneering state-of-the-art architecture and technology of the SZDLC project are presented. Firstly a report on basic results of advanced energy modelling and simulation in the planning phase and for the certification method is given and secondly the authors publish energy performance data of the operating solar heat driven absorption cooling system.

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Peer-review by the scientific conference committee of SHC 2015 under responsibility of PSE AG

Keywords: LEED™, Arabian Green Building, Simulation, Solar Thermal Cooling, Energy Performance Assessment;

1. Introduction

A gigantic sustainable tourism project is taking shape in the city of Al Ain by order of the government in Abu Dhabi – a 400-hectar wildlife park and resort with hotels, themed safaris, residential areas and the associated infrastructure. The first building to go up as part of the master plan was the Sheikh Zayed Desert Learning Center

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Peer-review by the scientific conference committee of SHC 2015 under responsibility of PSE AG
doi:10.1016/j.egypro.2016.06.249

SZDLC, planned as a museum and research Centre for desert environments and ecological issues. Pioneering state-of-the-art architecture and technology, this building proves that sustainable building concepts can be implemented in desert locations, too. The aim was to reduce environmental impact and life-cycle costs significantly with the aid of innovative designs and technologies. The project was designed by *Chalabi Architekten & Partner*, acting as lead consultant, in a comprehensive process, and implemented largely with Austrian contractors and in collaboration with scientific partners. The SZDLC has been already certified in the US program LEED™ (Leadership in Energy and Environmental Design) with the LEED™ Platinum Standard [1]. A key issue in hot and dry climates is how to cool buildings energy efficient and with high indoor quality. Herewith the SZDLC is definitely a show case how the architectural design significantly reduce the cooling demand. The SZDLC building is partially submerged into the ground and activates passively its thermal building mass. The design implies only low areas of transparent façade elements. Nevertheless the cooling demand has to be covered by further active measures. This publication focuses on the achievements of the scientific support during the planning phase and on the energy performance on the solar heat driven cooling system. Fig. 1 shows a rendering of the architectural design of the SZDLC building.

Fig. 1 Rendering - Architectural model East view (Chalabi Architekten & Partner)

2. Scientific support in planning phase and LEED™ certification

2.1. Support in planning phase

Due to high innovative character of the building project a research partner joined the planning team and was in charge to perform selected building and system simulation for supporting the security in planning. Herewith exemplarily the energy modelling results of the thermal performance of an air-soil heat exchanger is highlighted. The design of the building and HVAC-systems for the Desert Learning Center includes buried horizontal air-channels and a so-called air to soil heat exchanger, to precool the fresh air for the ventilation system. Due to the parametric studies conducted in the simulation environment TRNSYS 16.1 [2] the finding is: The air-soil heat exchanger design with 8 pipes, 1.2 m in diameter each and an average length of 110 m, buried at a depth of 5 meters (top edge) lead to temperature decrease in between 12.8 K to 18 K depending on the considered total volume flow 50,000 m^3/hr and 15,000 m^3/hr.

2.2. Energy modeling for LEED™ certification

The number of renewable energy features and systems makes the building energy performance analysis complex to model and analyze. Challenging features of the Sheikh Zayed Desert Learning Centre include;

- Thermally massive building envelope
- Complex shape of building and thermal zones
- Large and complex HVAC network
- Concrete core activation for cooling

- Solar thermal absorption cooling
- Fresh air pre-cooling using a soil-air heat exchanger
- Exhaust air enthalpy recovery
- Electricity generation by photovoltaic

The scientific partner of the SZDLC planning team was in charge to model and simulate the entire building and its HVAC systems according to the LEED™ requirements. Within LEED™ for New Construction 2.2, the relevant section for energy performance is the credits for Energy and Atmosphere (EA). This report details the procedure taken within “EA credit 1 - Optimize Energy Performance” and EA Credit 1 credits energy performance improvements compared to a Baseline building. The Baseline building is defined in “ASHRAE Standard 90.1 - Energy Standard for Buildings except Low- Rise Residential Buildings”. This method is referred to as “Option 1 - Whole Building Simulation” for LEED™ credit EA 1. To comply with Option 1, the building as it is currently designed (the As-Designed model) is modeled and simulated to predict its energy performance (annual energy consumption). From the As-Designed building, a similar model is constructed using ASHRAE 90.1 which meets the minimum standard (the Baseline building).

Building modelling

The complex geometry of the building requires an abstraction to derive an appropriate thermodynamic representation from the architectural model. Therefore, the structure is divided into thermal zones, which partly represent actual zones of the building (Entrance, Offices, Toilets, Theatre ...). Due to the exhibition area being an open space expanding from the bottom to the top level of the building, this part of the building was sub-divided into smaller zones in order to represent the actual thermal behavior with greater accuracy. The thermal zones of the building model in Fig. 2 are summarized according to floor area and volume, and the corresponding LEED™ categories in Table 1. The necessity of abstracting the architectural model to get to its thermodynamic representation implies that the figures for the floor area and zone volume in Table 1 may differ slightly from the design figures.

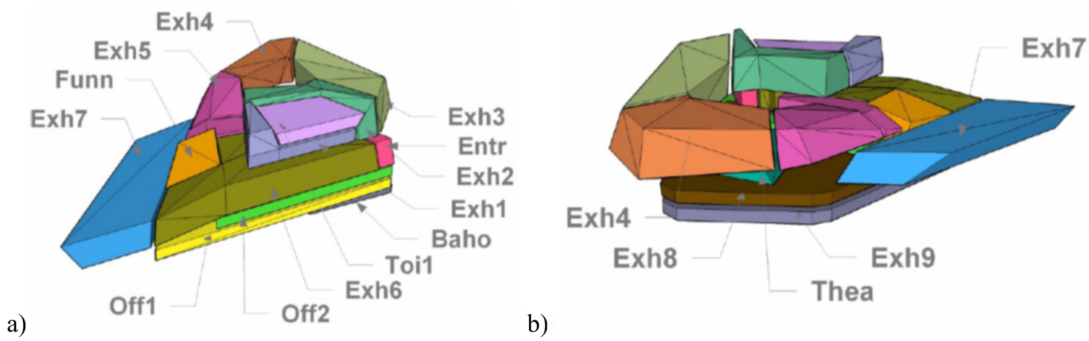

Fig. 2 Thermodynamic zoning – a) Front view and b) back view (AIT)

Table 1 Thermal zones and space summary

zone name	LEED category	floor area conditioned	floor area unconditioned	air volume
-	-	[m²]	[m²]	[m³]
Exhibition 1	Dining Area	350	-	1823
	Sum	**350**	-	**1823**
Exhibition 2	General Exhibition	340	-	2978
Exhibition 3	General Exhibition	677	-	5594
Exhibition 4	General Exhibition	437	-	3597
Exhibition 5	General Exhibition	547	-	2870
Exhibition 6	General Exhibition	825	-	6284
Exhibition 7	General Exhibition	769	-	4626
Exhibition 8	General Exhibition	1634	-	5321
Exhibition 9	General Exhibition	1634	-	4470
Funnel	General Exhibition	100	-	1714
	Sum	**6963**	-	**37454**
Office 1	Offices Enclosed	921	-	2762
Office 2	Offices Enclosed	921	-	2762
	Sum	**1842**	-	**5524**
Theatre	Audience	542	-	4863
	Sum	**542**	-	**4863**
Toilet 1	Restrooms	257	-	942
Toilet 2	Restrooms	93	-	278
Toilet 3	Restrooms	148	-	443
	Sum	**498**	-	**1663**
Entrance	Lobby	102	-	680
	Sum	**102**	-	**680**
Back of house	Equipment Room	-	2416	8330
	Sum	-	**2416**	**8330**

Building physics

Table 4.2 lists various construction elements used in the building model and their corresponding U-values and g-values. These values are calculated based on each individual construction with TRNSYS standard heat transfer coefficients from solid materials to the air. Table 4.3 shows the U-values and g-values for the construction elements used in the Baseline simulation model. These values were implemented according to ASHRAE Standard 90.1-2004 (Reference ASHRAE 90.1)

Table 2 U-values and g-values for As Designed and Baseline construction

		AS DESIGNED		**BASELINE**	
	model	**U-value**	**g-value**	**U-value**	**g-value**
Name	**Construction element**	**[W/m²K]**	**[-]**	**[W/m²K]**	**[-]**
WA01	external wall	0.261	-	0.705	-
WA02	external wall (internal spiral)	0.239	-	0.705	-
WA04	external wall touching ground	0.359	-	0.705	-
RO01	roof	0.178	-	0.36	-
RO02	roof (light construction)	0.175	-	0.36	-
RO03	roof (theatre)	0.224		0.36	-
RO04	roof (cooling towers)	0.221	-	0.36	-
FL01	floor (touching ground)	0.266	-	1.264	-
FL02	floor	0.206	-	1.986	-
FL03	floor (above basement)	0.717	-	1.986	-
ST01	staircase	0.254	-	0.254	-
WI01_1	fenestration general	1.1	0.22	6.93	0.25
WI01_2	fenestration east facade	1.1	0.32	6.93	0.61

Building Simulation

The building envelope with internal thermal loads was simulated in the given climate for a whole year in different configurations. The thermal loads include occupancy and artificial lighting. Due to different fresh air requirements in the As-Designed and Baseline buildings and subsequently different ventilation systems, ventilation of fresh air is not taken into account. These demand simulations represent a first approach to determining the building thermal behavior and the energy demanded.

These simulations calculate the required thermal energy that is required to keep the air conditions for each of the zones at the defined set-point (below 25°C and 50% relative humidity) for all hours of the year. The building envelope cooling energy is therefore defined as the cooling required maintaining the interior space air temperature at comfort conditions with no ventilation air requirement. Fig. 3 shows the total annual energy demand required for cooling and dehumidification (heating and humidification was not necessary at any time) for five different configurations of the SZDLC. Energy required for ventilation (fresh) air is not considered in this graph. The first variant represents the SZDLC as it is designed and requires 1,220 MWh_{th} per year for cooling and 116 MWh_{th} per year for dehumidification. The additional four configurations are four different orientations of the Baseline building. For the Baseline model, the average energy demand is 2,094 MWh_{th} per year for cooling and dehumidification is 116 MWh_{th} per year for dehumidification. The building cooling demand required to manage the indoor comfort without considering ventilation air of the As-Designed model, is therefore expected to be reduced by approximately 800 MWh_{th} per year compared to the Baseline design. This represents an improved performance of 41.7%. This thermal energy savings can be considered within the context of all primary energy requirements for the building.

It is important to note that this 800 MWh_{th} per year of energy savings is not utility electrical energy but thermal energy. In the Baseline and As-Designed buildings, this cooling demand is met by a variety of systems. These systems supply the cooling energy required by converting other forms of energy. For example, a vapor compression chiller uses electrical energy to transfer energy from the chilled water to cooling water, a process which has a typical coefficient of performance, or conversion ratio higher than 3. The modelling and the simulation of the HVAC system was conducted as well in the course of LEED™ certification process, the author decided not to document on this especially in this paper.

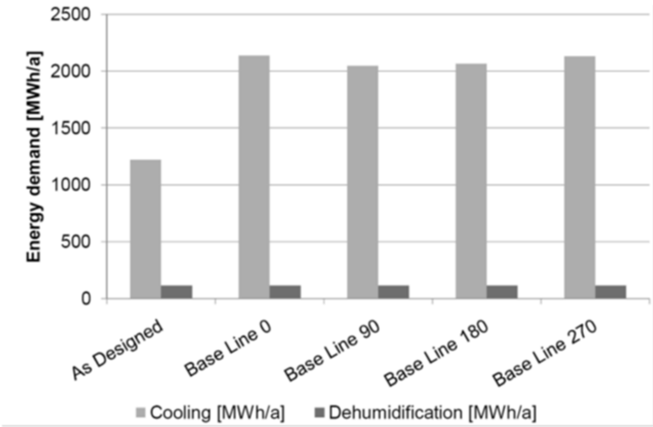

Fig. 3 Comparison - Annual energy demand cooling and dehumidification

Concrete core activation

In the HVAC design concept the thermal activation of building element to extract heat from the building was considered and finally implemented in the construction phase. The cold water production systems are coupled to thermally activated building elements, i.e. cold water flows through pipes integrated in the building‘s floors, walls and ceilings. In the design phase AIT modelled the concrete core system CCA and performed advanced building simulation in order to determine the amount of heat which potentially can be extracted from building elements. Fig. 4 shows the performance of the concrete core system over the year. The set-point of 16 degree Celsius is supplied by the solar absorption chilled water system and maintained by the primary conventional chiller. The return temperature of the concrete core activation system is fairly constant over the year, showing that the system is supplying a base cooling load for the Sheikh Zayed Desert Learning Centre. The base load of the CCA is between 200 and 300 kW_{th}.

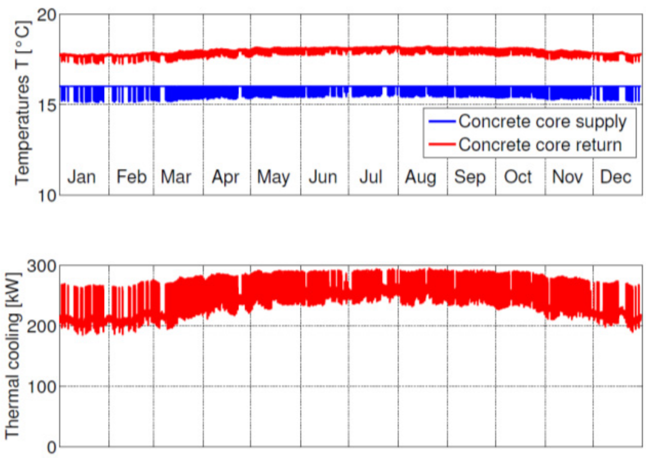

Fig. 4 Simulated annual cooling performance of the concrete core activation

3. Solar heat driven cooling system

Key technical data of the solar cooling system [3]:

- Cooling capacity of lithium/bromide absorption chillers: 352 kW
- Collector: 1.134 m² gross area high temperature flat plate collectors/ Slope: 25°
- Capacity of hot-water storage tanks: 2x13 m³
- Capacity of cold-water storage tank: 5 m³
- Heat rejection: 6 closed-circuit cooling towers in conjunction with compression chiller

Measurement data from monitoring is available for 2013 and 2014. Electrical efficiency could not be measured as the absorption chiller uses the same cooling towers as the compression chillers and the heat rejection is one of the major consumers of electricity in a solar cooling system. Between 2013 and 2014 major improvements in terms of solar thermal yield and cold production could be reached. Fig. 5 shows for example the temperature in the solar circuit was decreased and thus the solar yields raised by 27 % from 2013 to 2014, with raises in each month compared to the month in the previous year, see Fig. 6. The specific solar yield increased from 756 kWh/m²/yr in 2013 to 962 kWh/m²/yr in 2014, both related to gross collector area.

Despite the decrease in solar thermal collector temperature and thus decrease in temperature at the generator of the absorption chiller machine (ACM), the cold production could also be increased. This was on one hand due to a lowering of the temperature of the chilled water coming from the cooling tower. Previously the cooling water temperature was higher than the pre-defined temperature. On the other hand there was a servicing of the absorption chiller machine. Here the correct vacuum was re-established.

The production of cold from the ACM was increased by 33 % from 2013 to 2014, with each month in 2014 with higher cold production than the respective month in 2013. Thus also the thermal EER of the ACM increased. From June 2013 to December 2014 it was in each month above 0.70, with maximum value of 0.73. Specific daily cold production related to collector area is between 1.36 kWh/m², day in December and 1, 74 kWh/m², day in September. This is a quite even distribution compared to areas which are more distant to the equator, like Central Europe.

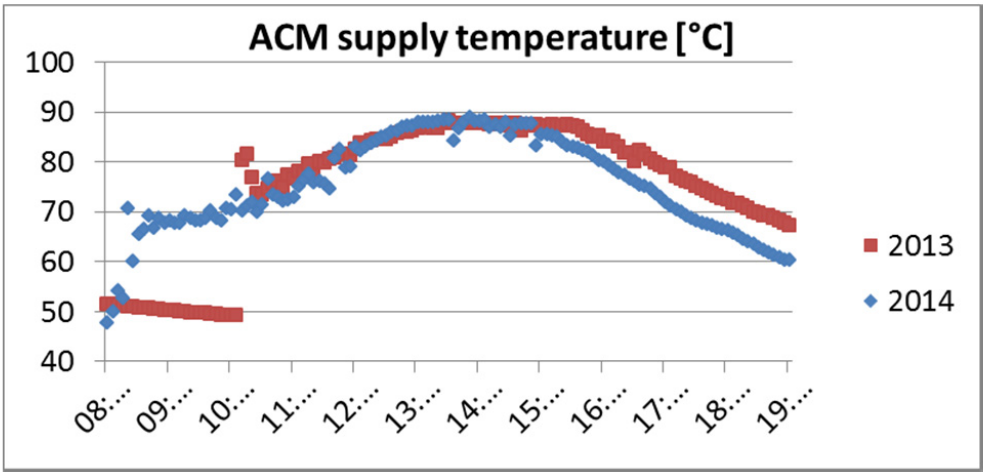

Fig. 5 Comparison of ACM supply temperatures on July 1st, of 2013 and 2014 respectively

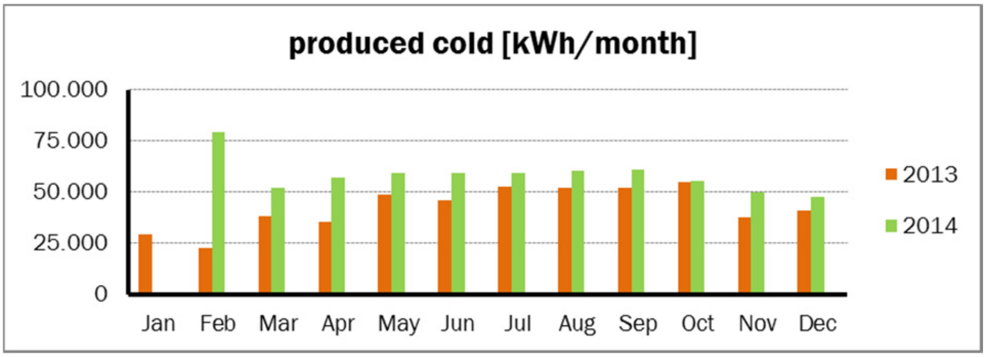

Fig. 6 Increased cold production between 2013 and 2014

4. Conclusion

The As-Designed and Baseline models were simulated for a typical year to calculate the amount of primary energy required to meet the operational demands of the building, including air conditioning, lighting, and other equipment loads. In the case of the SZDLC the building is connected to the electric grid and all other energy is locally generated or transformed. The annual sum of primary energy consumption by the As-Designed and Baseline model is then compared, where the As-Designed model consuming less energy than the Baseline model. Simulation results support that the As-Designed model consumes 36.2% less primary energy than the Baseline model. According to LEED™, this results in 8 credit points [4].

This project demonstrates once again that a solar thermal cooling system needs monitoring and adjustments during start-up phase in order to reach the planned performance.

This project proofs that an intelligent mix of natural based architectural design, innovative technologies and the local use of renewable energy sources reduces the environmental impact and life-cycle costs significantly in desert locations too.

Acknowledgements

The Austrian Institute of Technology thanks the Vienna partnership of architects Chalabi Architekten & Partner being selected as part of this cutting-edge flagship project - the Sheikh Zayed Desert Learning Center, implemented in the United Arab Emirates and completed in 2014.

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